

sPHENIX Hadronic Calorimeter Prototype Test Beam Analysis

Liang Xue

Georgia State University

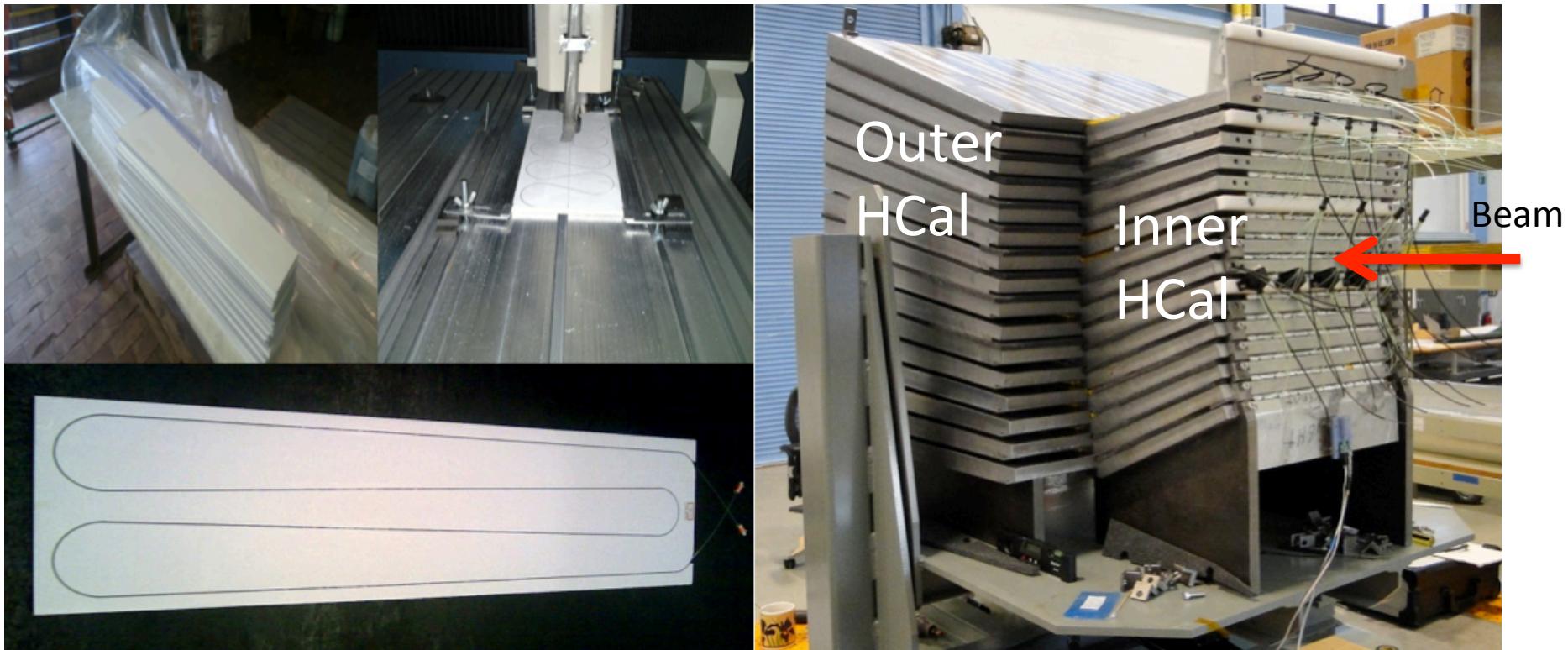


Outline

- The first HCal prototype was constructed and tested at the Fermilab test beam facility in February of 2014, as John Haggerty mentioned earlier.
- The test beam data has been analyzed to study the detector performance.
- GEANT4 simulation studies of the HCal prototype has been performed, and compared with the test beam results.

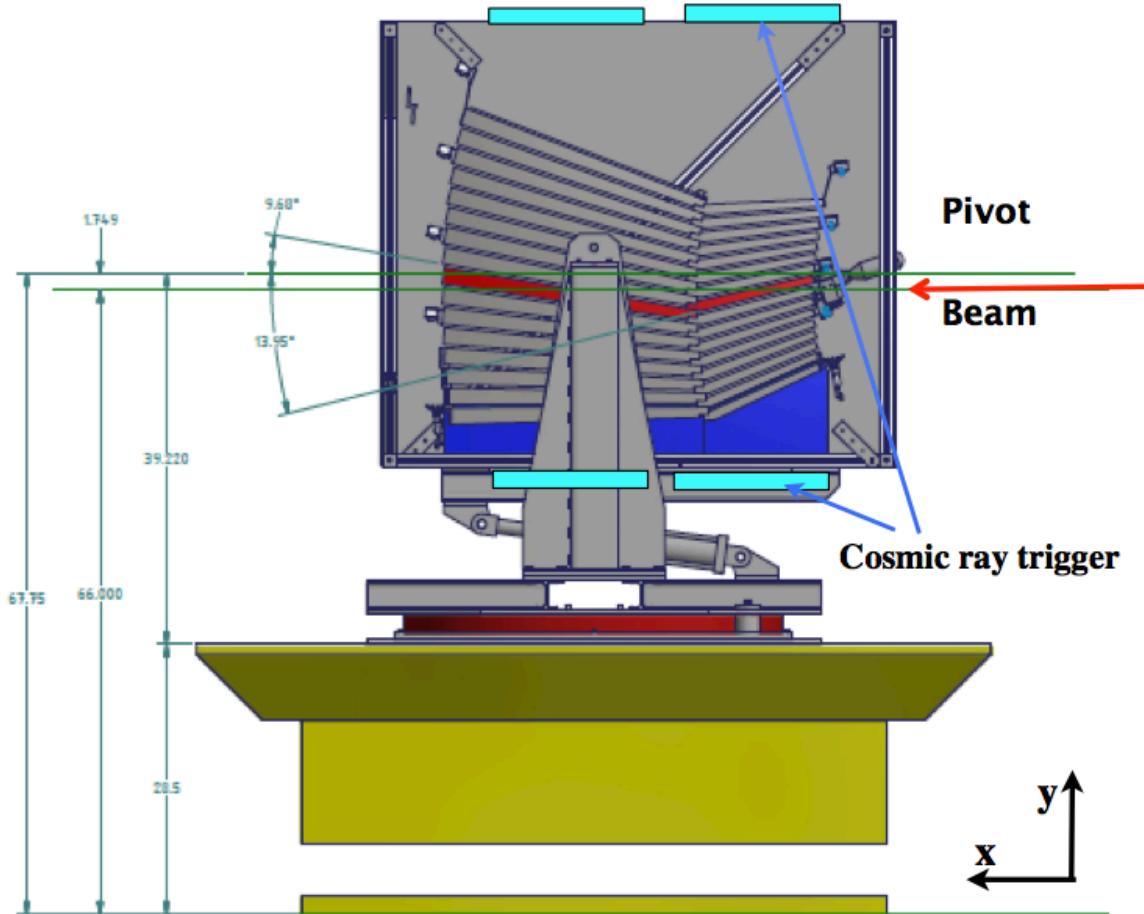
HCal Prototype Detector

- Two segments (inner and outer), 16 layers of steel/scintillator plates in each segment. Dimension: 1.2m x 1.7m x 1.3m (w x d x h), ~8,000 lbs in weight.
- Each segment is divided into 16 towers and read out with SiPM.



FNAL Test Beam Setup

- Four scintillator panels at the top and bottom are used as a trigger device for cosmic ray calibrations.
- The prototype can be rotated along y- and z-axis and moved along x- and y- direction.
- Test beam energies range from 4 GeV to 60 GeV.



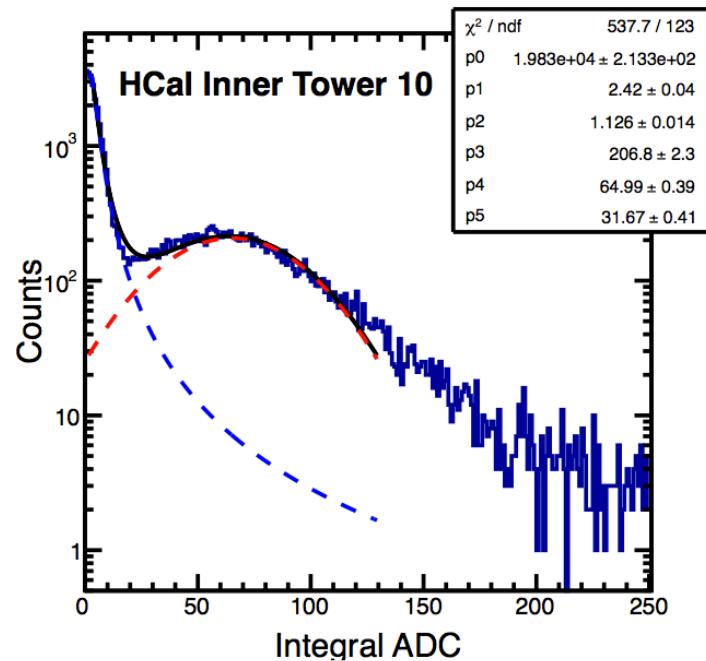
Shower Energy Reconstruction

Tower energy reconstruction

$$E(ch) = I(ch) \times \frac{E_{dep}^{cosmic}(ch)}{ADC_{dep}^{cosmic}(ch) \times SF(muon)},$$

Hadronic shower Integrated ADC
↓
Cosmic signal Integrated ADC

Simulated Cosmic ~5.5MeV
↓
Simulate sampling factor



- We used cosmic ray data to convert ADC value to the energy scale.
- The total energy in each HCal segment is determined by summing up the energies in all 16 towers in the segment.

Determine the Beam Composition

Energy Asymmetry: $E_{asy} = \frac{E1 - E2}{E1 + E2}$

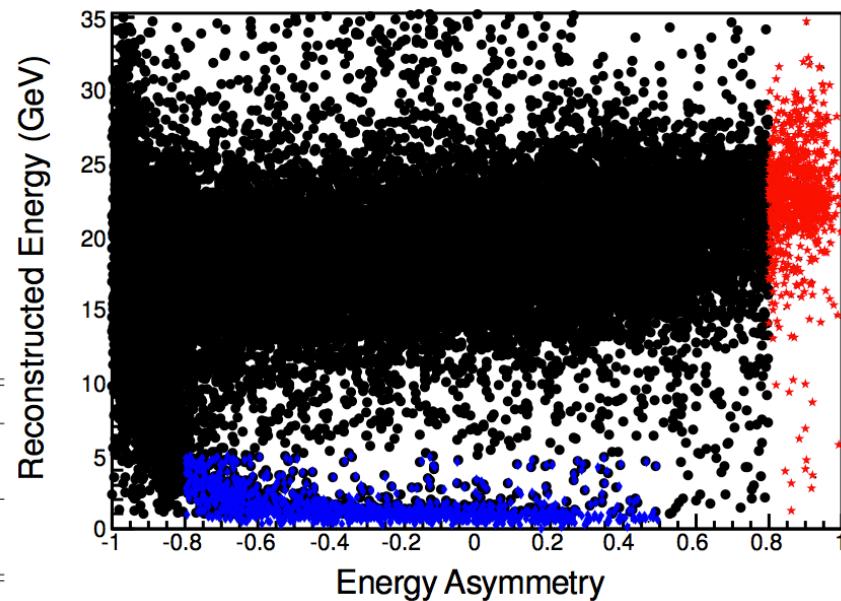
Hadronic : Deep shower in HCal

EM : Shallow shower in HCal

MIP: Less deposited energy

Beam Energy	Pions	Electrons	Muons
≤ 8 GeV beam	$E_{total} > 1$ GeV $-1.0 < E_{asy} < 0.8$	$E_{total} > 1$ GeV $0.8 < E_{asy} < 1.0$	$E_{total} < 2$ GeV $-0.8 < E_{asy} < 0.5$
> 8 GeV beam	$E_{total} > 1$ GeV $-1.0 < E_{asy} < 0.8$	$E_{total} > 1$ GeV $0.8 < E_{asy} < 1.0$	$E_{total} < 5$ GeV $-0.8 < E_{asy} < 0.5$

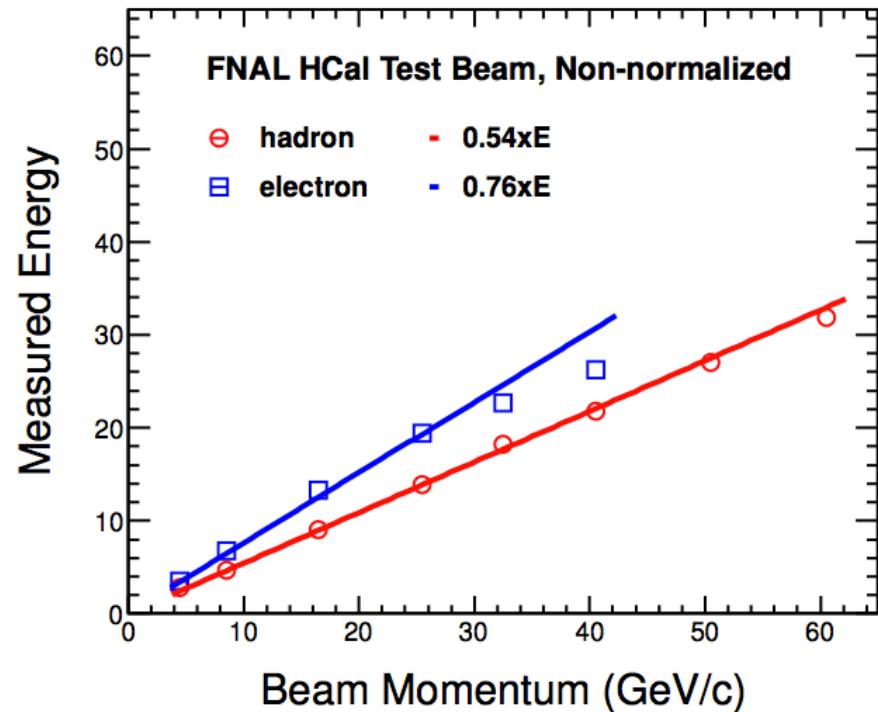
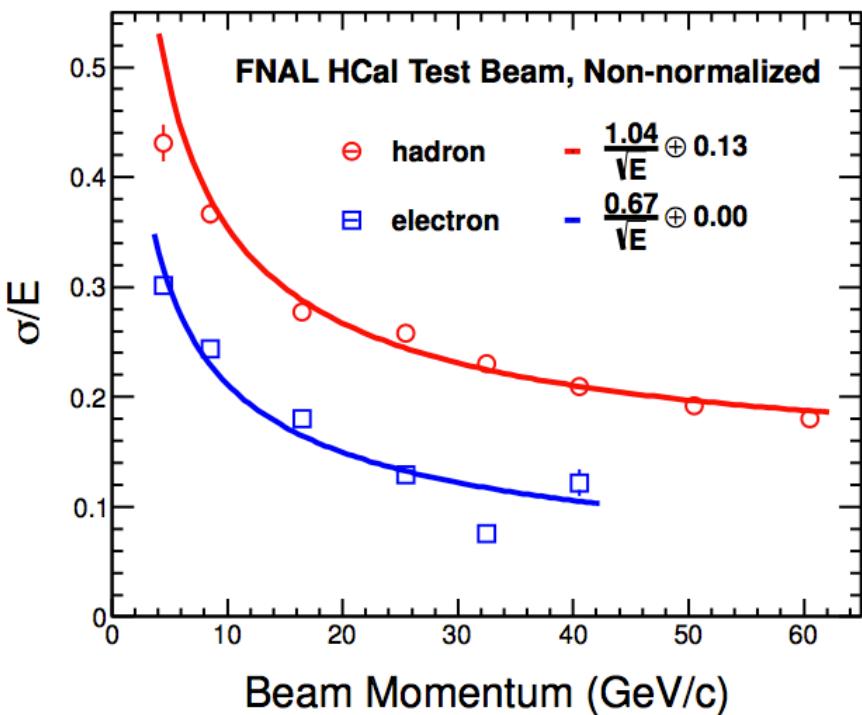
32 GeV Test Beam



**Test Beam
Composition:**

	4 GeV	8 GeV	16 GeV	25 GeV	32 GeV	40 GeV	50 GeV	60 GeV
pion	32.1%	39.8%	67.2%	85.7%	91.9%	94.6%	96.5%	97.2%
electron	63.7%	56.4%	26.1%	8.9%	3.7%	1.6%	0.6%	0.3%
muon	4.2%	3.8%	6.7%	5.4%	4.4%	3.8%	2.9%	2.5%

Energy Resolution & Linearity

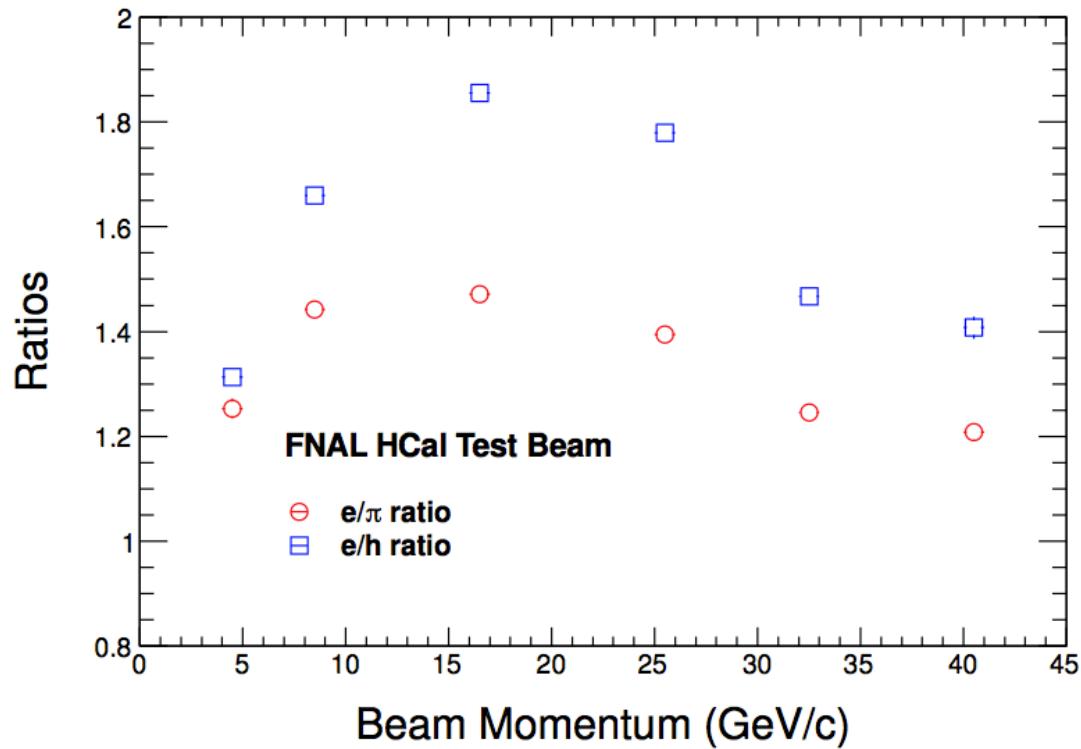


- Energy resolution is determined to $104\%/\sqrt{E} \oplus 13\%$.
- Good energy linearity.

e/π, e/h ratios

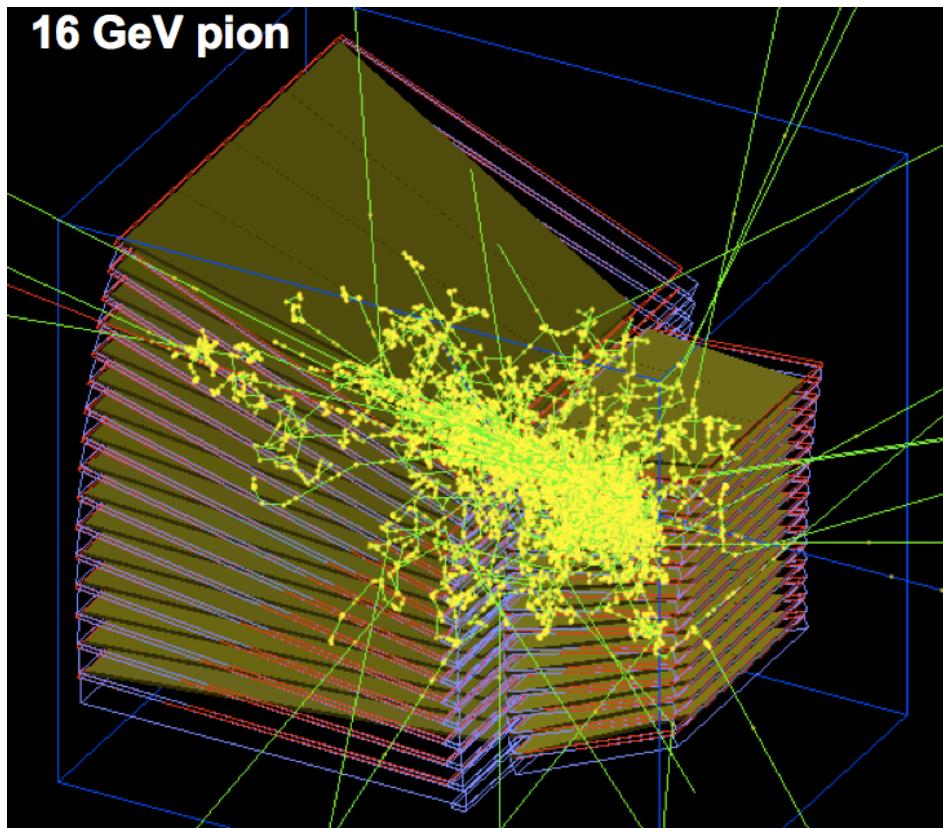
$$e/\pi = \frac{\langle E_e \rangle}{\langle E_\pi \rangle}$$

$$e/h = (e/\pi) \times \frac{1 - f_{\pi^0}}{1 - (e/\pi)f_{\pi^0}}$$



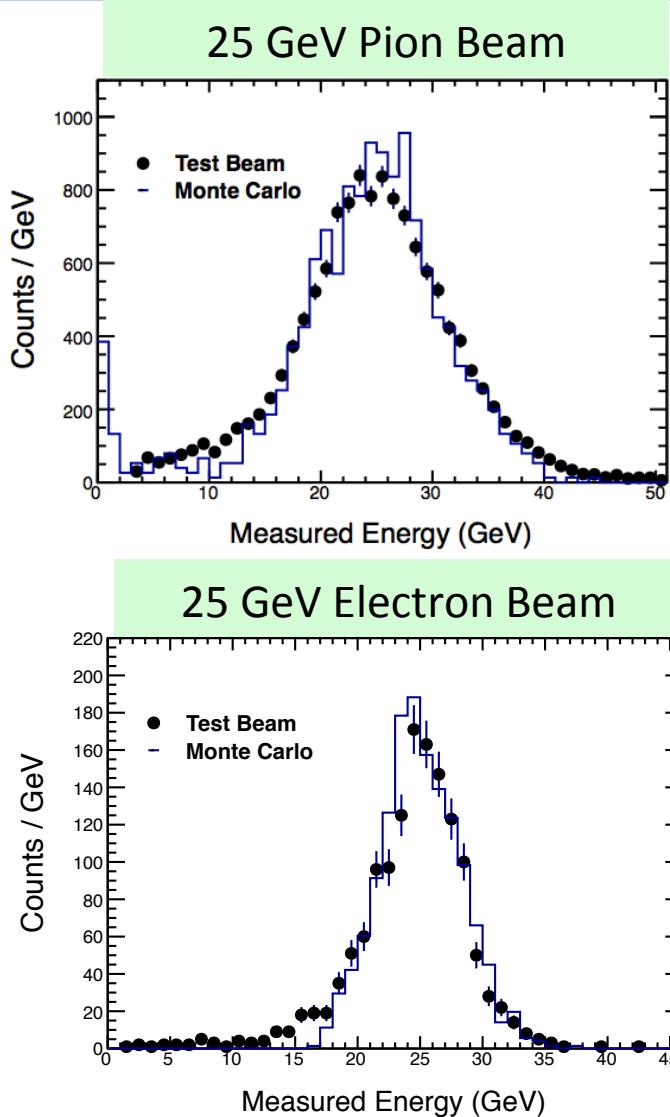
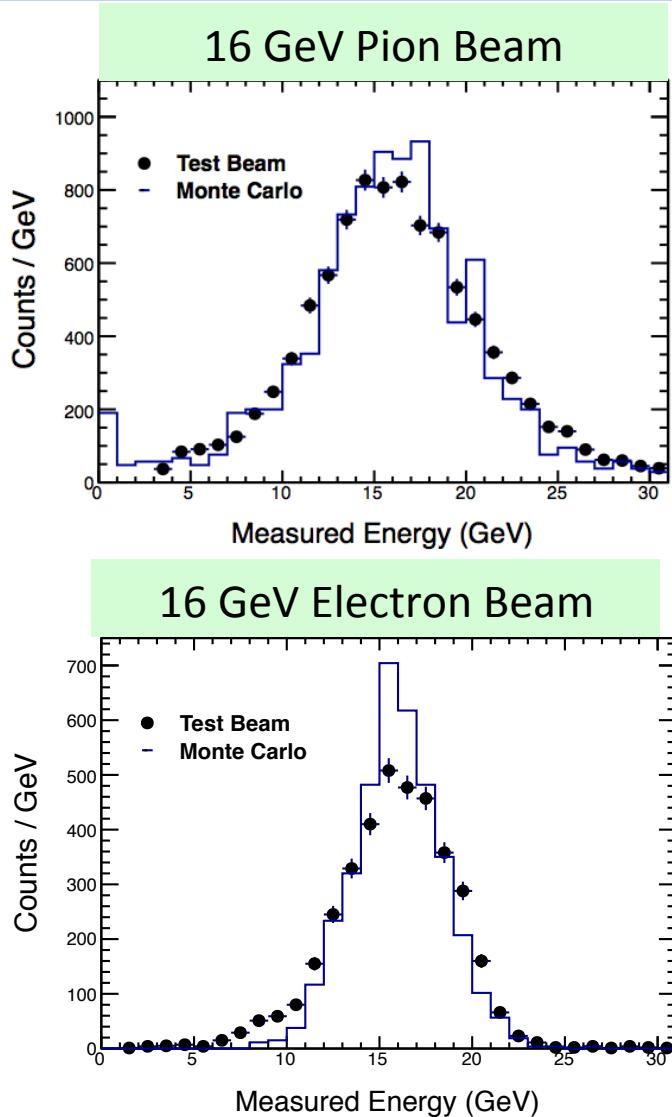
- e/π ratio is calculated via $\langle E_e \rangle / \langle E_\pi \rangle$, where $\langle E_e \rangle$ and $\langle E_\pi \rangle$ are the total reconstructed raw energy for e- and pion beam.
- e/h ratio is determined as a function of incident energy based on the e/π ratios.

GEANT4 Simulation



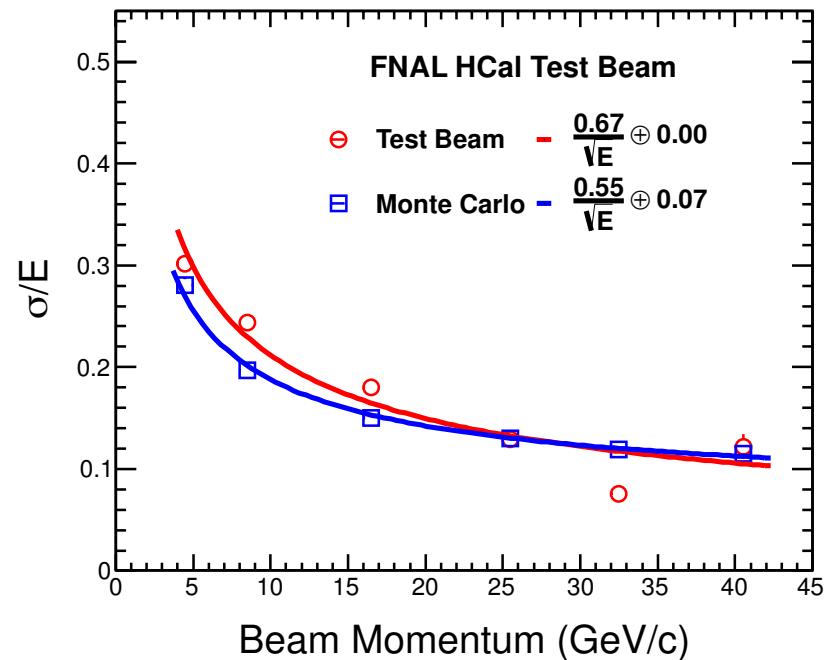
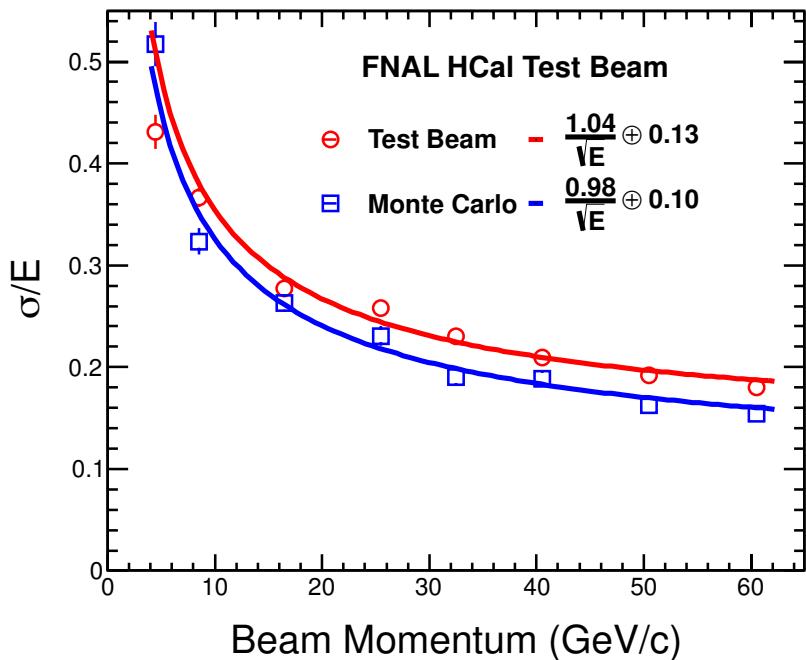
- Simulated single particles to determine energy resolution and compare with the test beam results.
- Determine the sampling fraction factors for each segment using muons.
- Determine the energy scale factors by simulation cosmic rays and comparing with the triggered cosmic ray data in test beam.

Test Beam / GEANT4 Comparison



- GEANT4 simulation reproduces the test beam energy spectra pretty well.

Test Beam / GEANT4 Comparison (cont)



- Energy Resolution between test beam and GEANT4 simulation are comparable.

Summary

- HCal prototype FNAL test beam data has been carefully analyzed and compared against the results from Geant4 simulation.
- The HCal energy resolution is determined to be $104\%/\text{sqrt}(E) \oplus 13\%$, which is comparable with that from GEANT4 simulation ($98\%/\text{sqrt}(E) \oplus 10\%$) for hadronic showers.
- e/π , e/h ratios have been evaluated using test beam data as a function of incident energy.

Backup Slides

Single Hadronic Shower

Energy Correction:

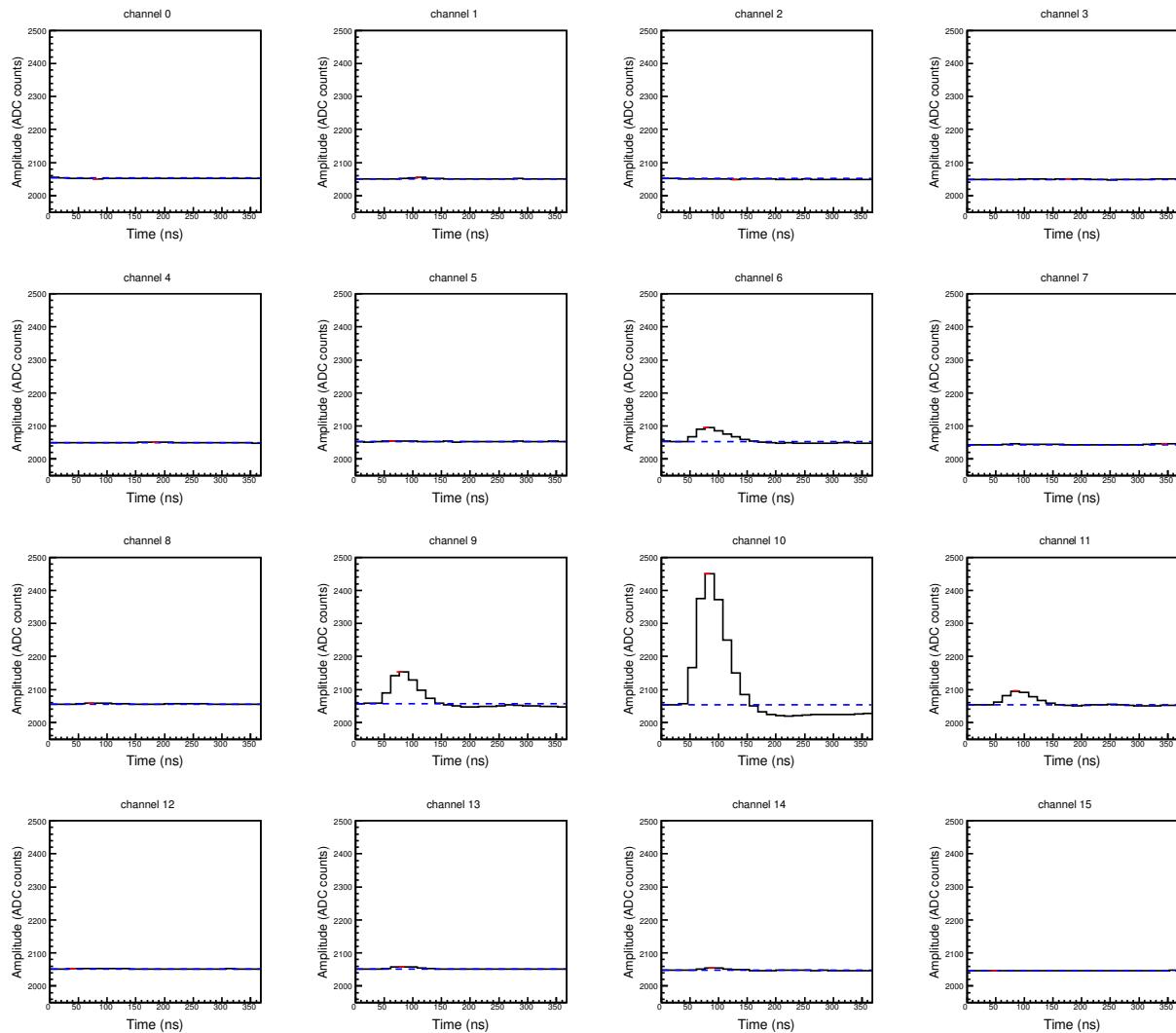
Integrated ADC
for hadronic
signals

Simulated cosmic
energy deposition in
each tower, ~5.5MeV

$$E(ch) = I(ch) \times \frac{E_{dep}^{cosmic}(ch)}{ADC_{dep}^{cosmic}(ch) \times SF(muon)},$$

Integrated ADC
for cosmic signals

Simulate sampling
factor from muons



- Energy in each channel are summed together to calculated total energy in each HCal Prototype segment.

e/π, e/h ratios

We are also able to calculate the e/π ratio using the reconstructed energy spectra. The ratio is calculated as follows

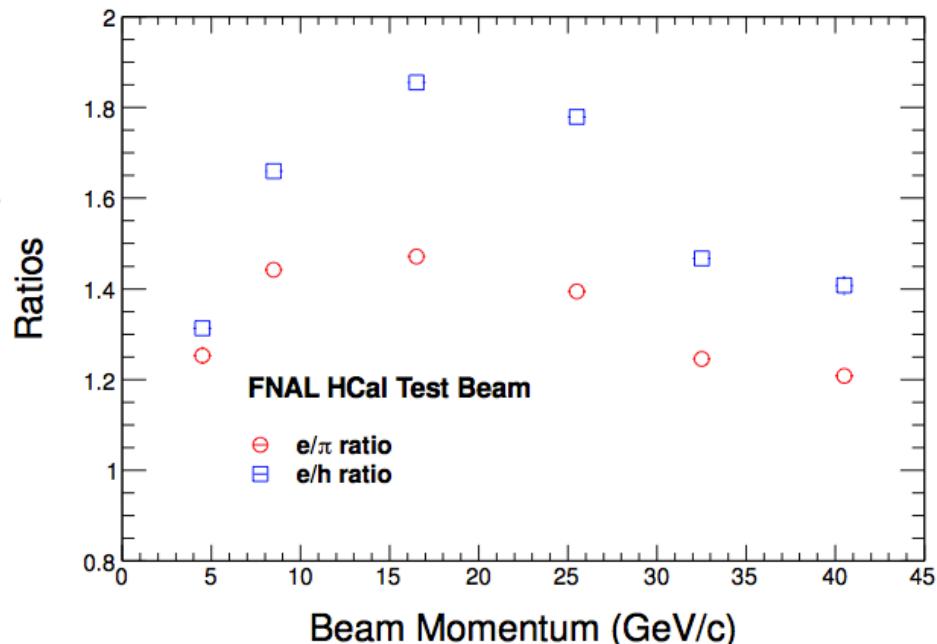
$$e/\pi = \frac{\langle E_e \rangle}{\langle E_\pi \rangle}, \quad (7)$$

where, $\langle E_e \rangle$, and $\langle E_\pi \rangle$ are the mean energy responses for electron and pions, respectively. And the e/h ratio is then determined by

$$e/h = (e/\pi) \times \frac{1 - f_{\pi^0}}{1 - (e/\pi)f_{\pi^0}}, \quad (8)$$

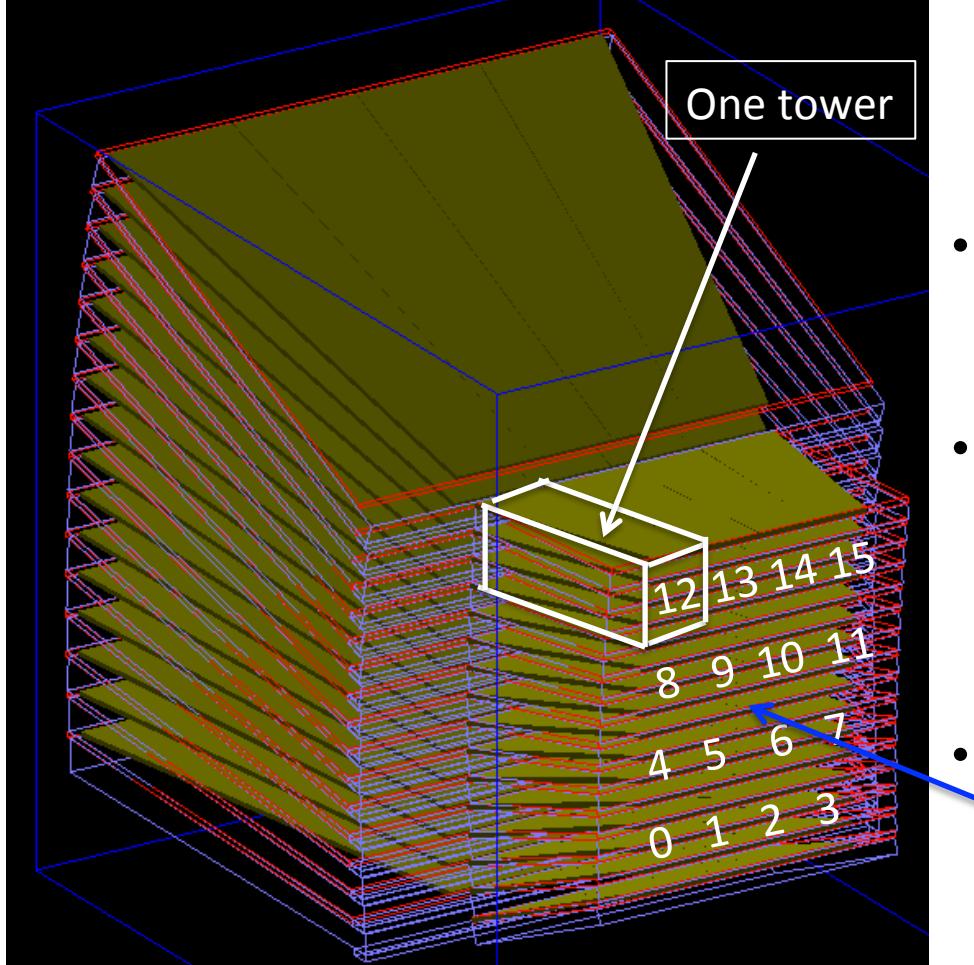
where $f_{\pi^0} = k \ln(E)$ is the average fraction of electromagnetic energy in the hadronic shower, and $k = 0.11$ [4].

e/π is defined as the ratio of energy response of e- and π beam at the same incident energy.



R. Wigmans, NIM A265 (1988) 273.

GEANT4 Simulation

- HCal prototype simulation work was done using sPHENIX simulation framework with GEANT4 version 10.0.2 toolkits (physics list: QGSP_BERT).
 - 1000 single mu-, e-, π - are generated shooting the center at 4, 8, 16, 25, 32, 40, 50, 60 GeV to study detector performance.
 - Cosmic rays was mimicked by lunched 4 GeV muon from the top of the detector for calibrations.
 - Energy is collected in each tower, and summed up in each segment by applying an tower threshold/suppression cut (0, 5, 10, 15, 20 MeV).
 - Reconstruct energy in each segment with total energy response divided by SF(H1/H2).
- 
- The diagram illustrates a 3D model of a HCal tower. The tower is represented by a series of green rectangular planes stacked vertically. A white wireframe cube is overlaid on the middle section, labeled with segment numbers 12 through 15. A blue arrow points from this cube to a vertical stack of segments labeled 0 through 7. A white box labeled "One tower" is positioned in the upper right corner of the tower's volume. Numerous red and blue lines represent particle tracks passing through the detector, originating from various directions and angles.

Cosmic Ray

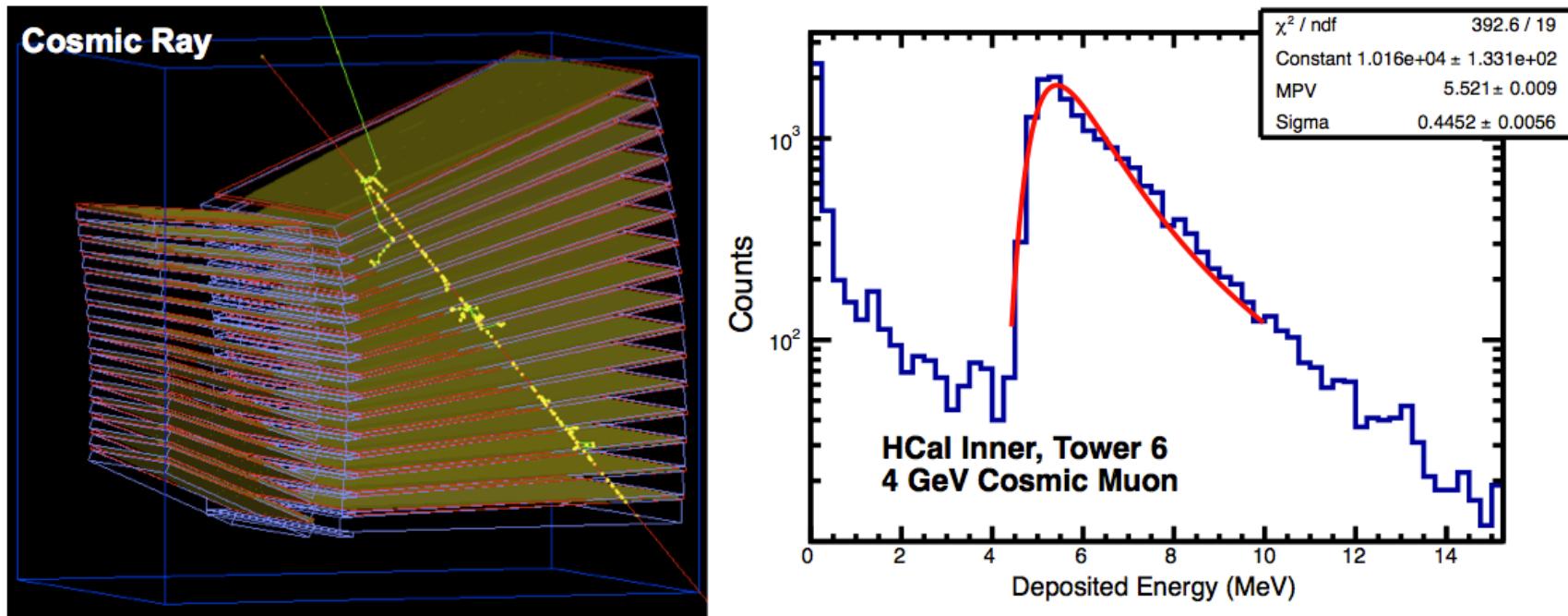
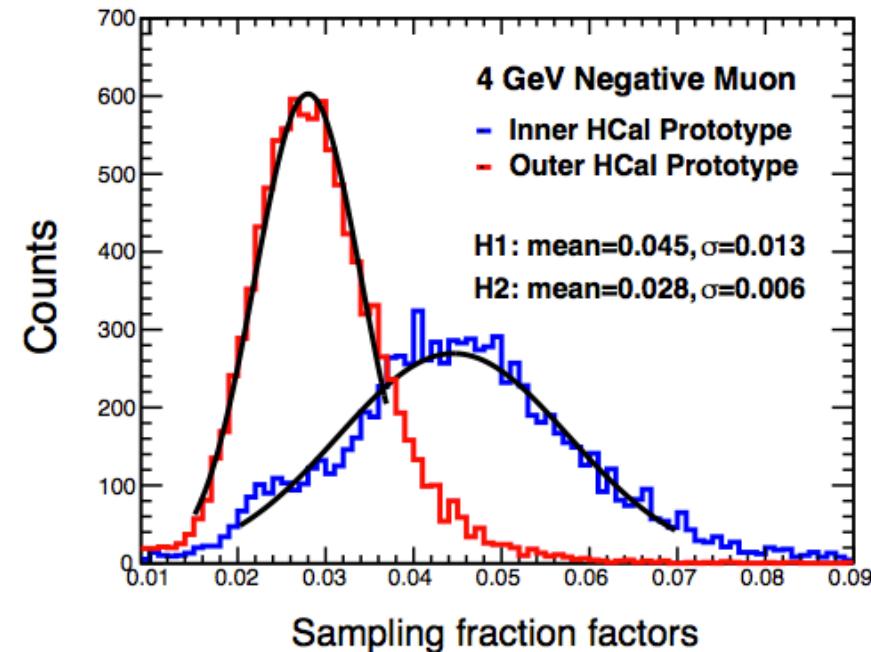
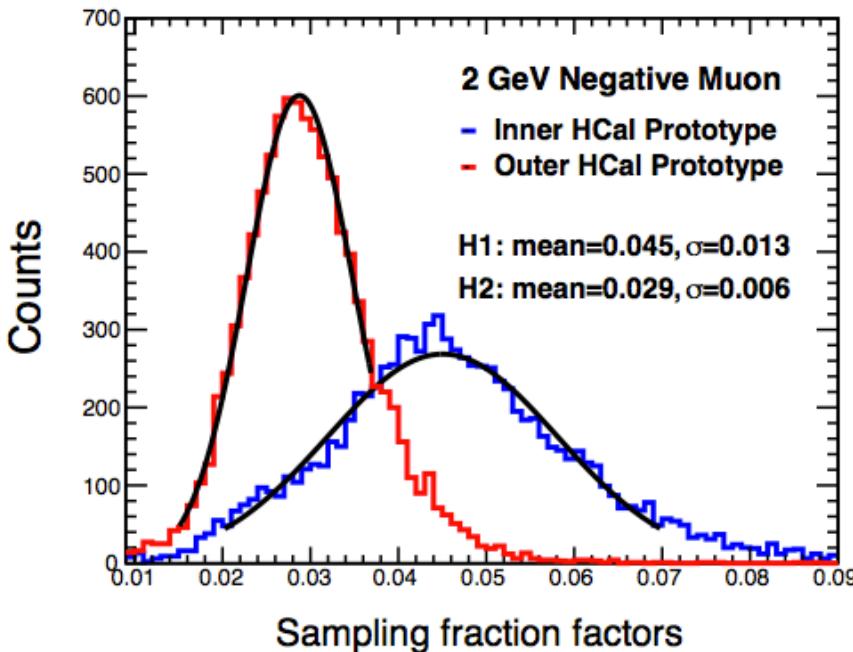


Figure 7: Event displays of cosmic ray simulation (left panel), and signal in H1 tower 6.

- Cosmic muons are simulated by launching 4 GeV muon at the top of the prototype detector with random angles downward.
- The deposited energy in each tower is fitted by Landau function, and the mean energy loss is ~ 5.5 MeV, which is used for the detector equalization calibration for test beam.

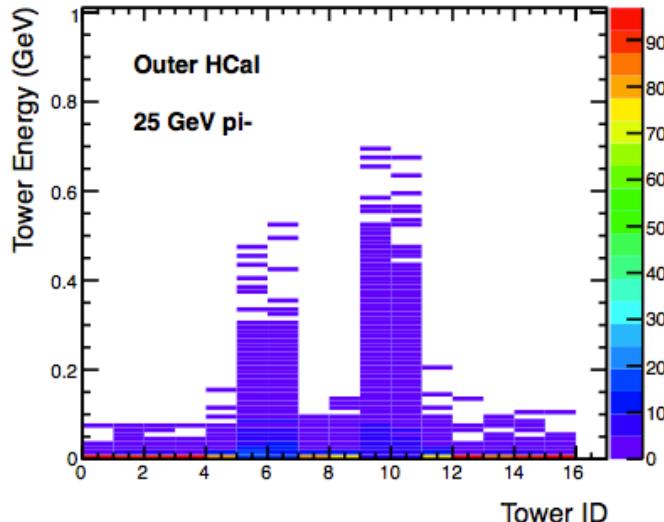
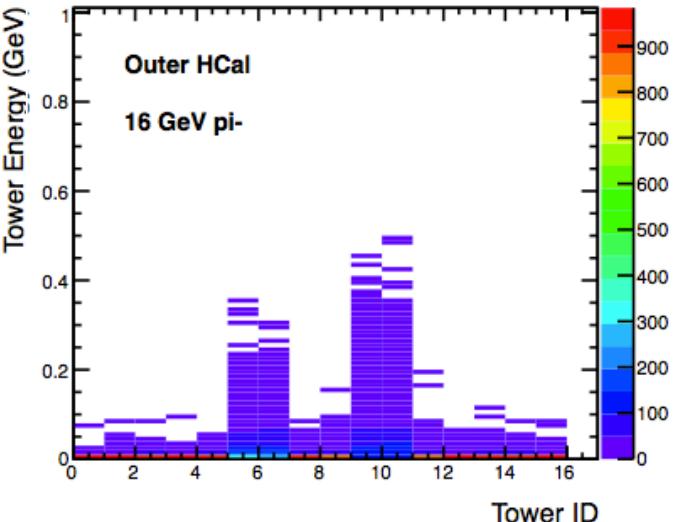
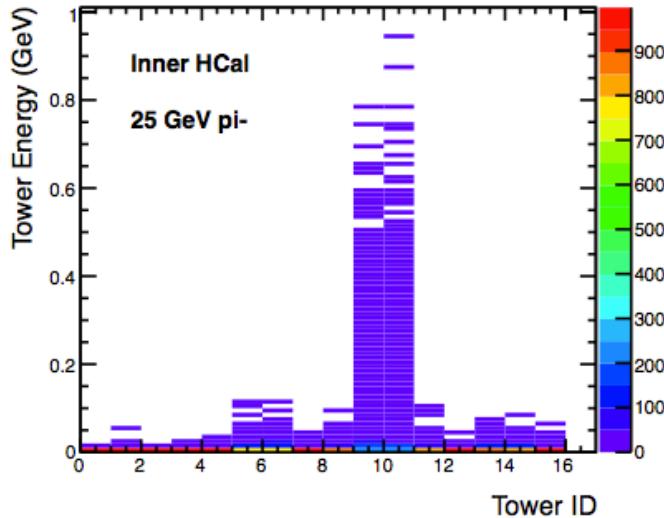
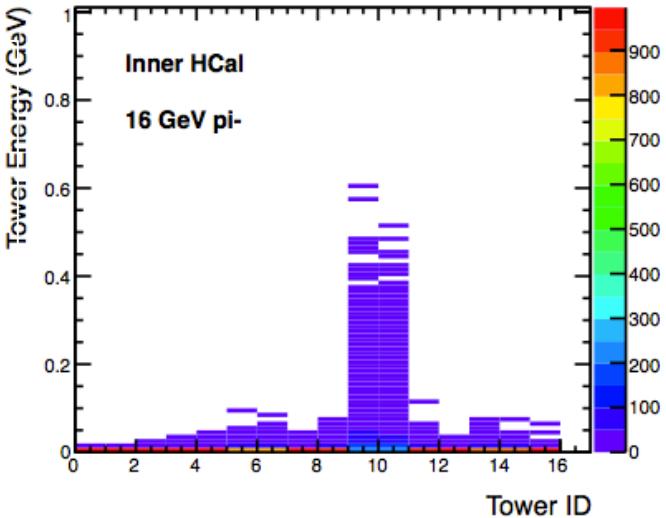
Sampling Fraction Factors

- To calculate the average sampling power of the HCal prototype. Single mu- are lunched from (0,0,0) and pass through the whole volume of the detector with different eat and phi angles.
- Sampling fraction factors of the detector is determined to be SF(H1)~4.5%, and SF(H2)~2.9% use single mu-.



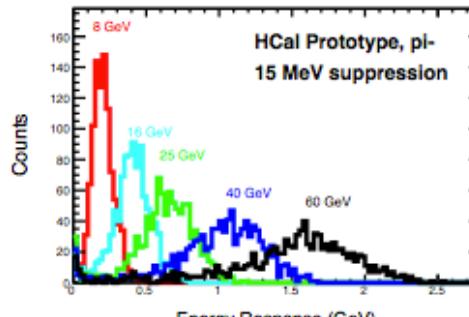
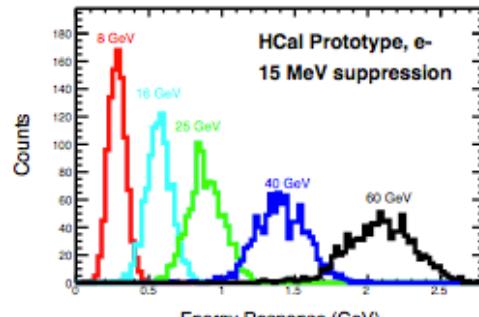
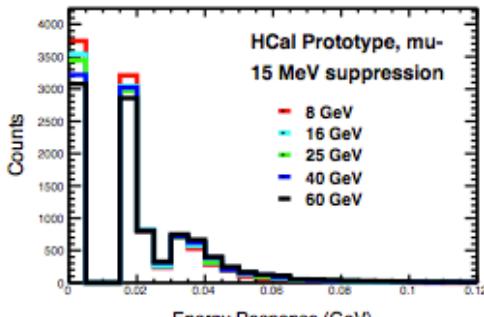
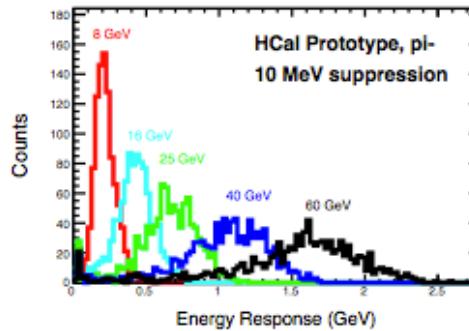
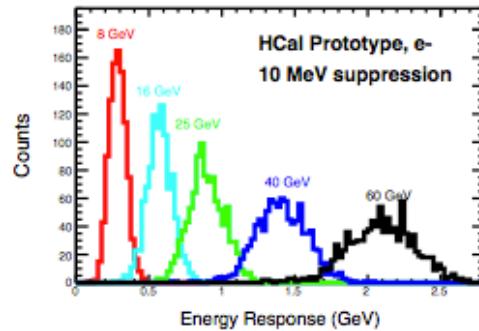
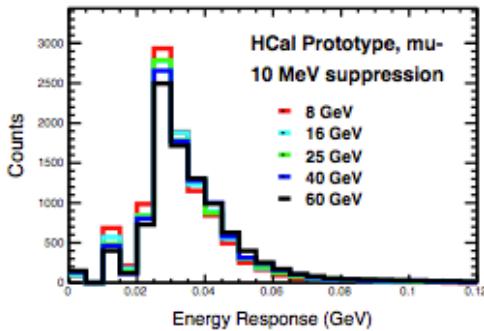
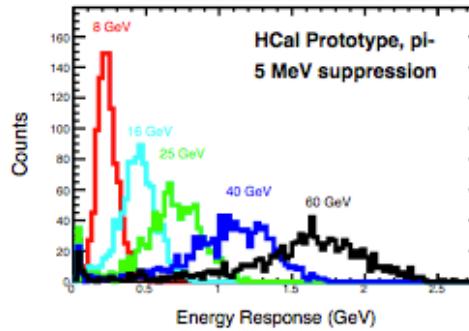
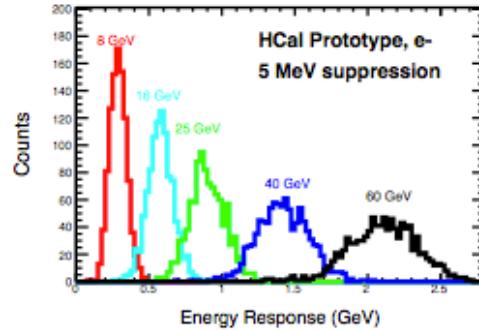
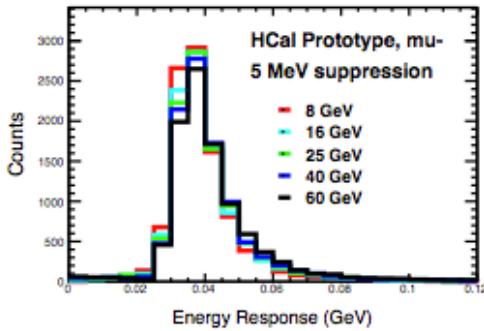
Tower Energy Responses

- Particles are launched shooting the center of the detector (tower 9, 10).
- Energy responses was calculated for each tower.



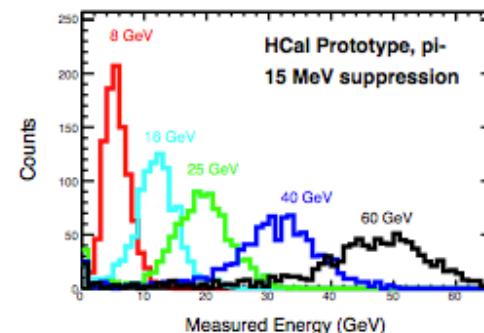
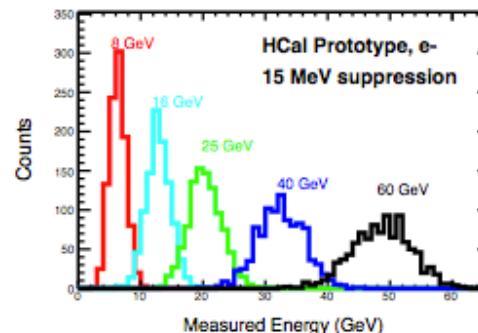
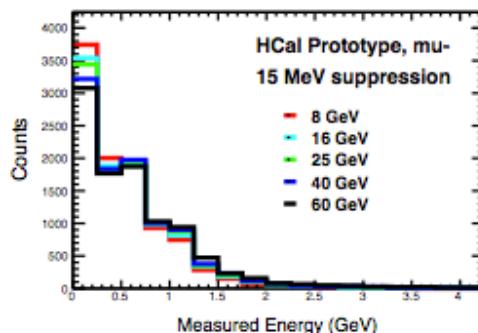
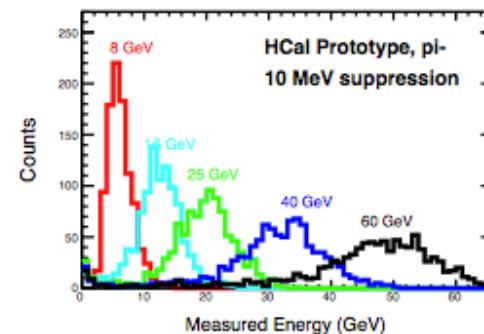
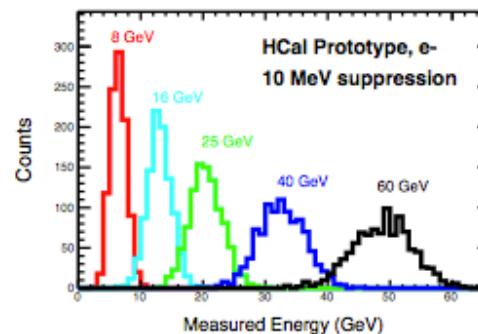
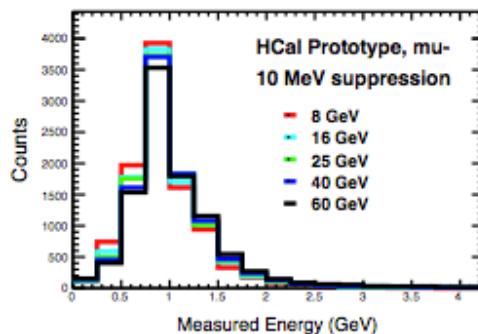
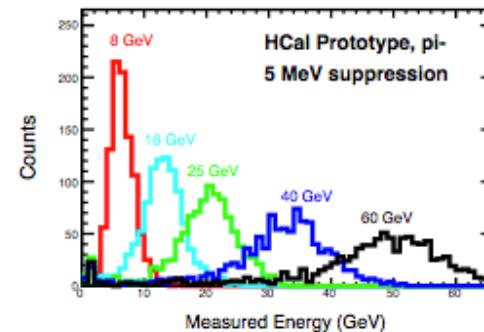
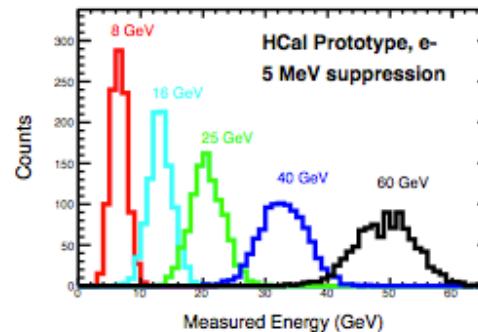
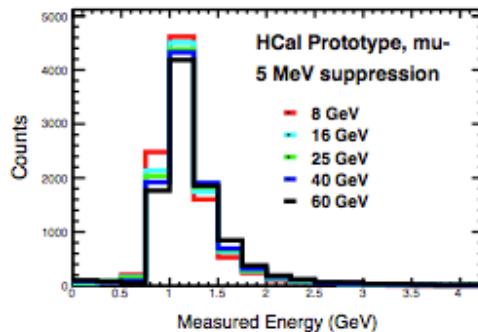
Total Energy Responses

Total energy response was calculated with different tower energy suppression levels (0, 5, 10, 15, 20 MeV).



Energy Spectra

Energy spectra was determined with energy response and the SF(muon) (0, 5, 10, 15, 20 MeV).

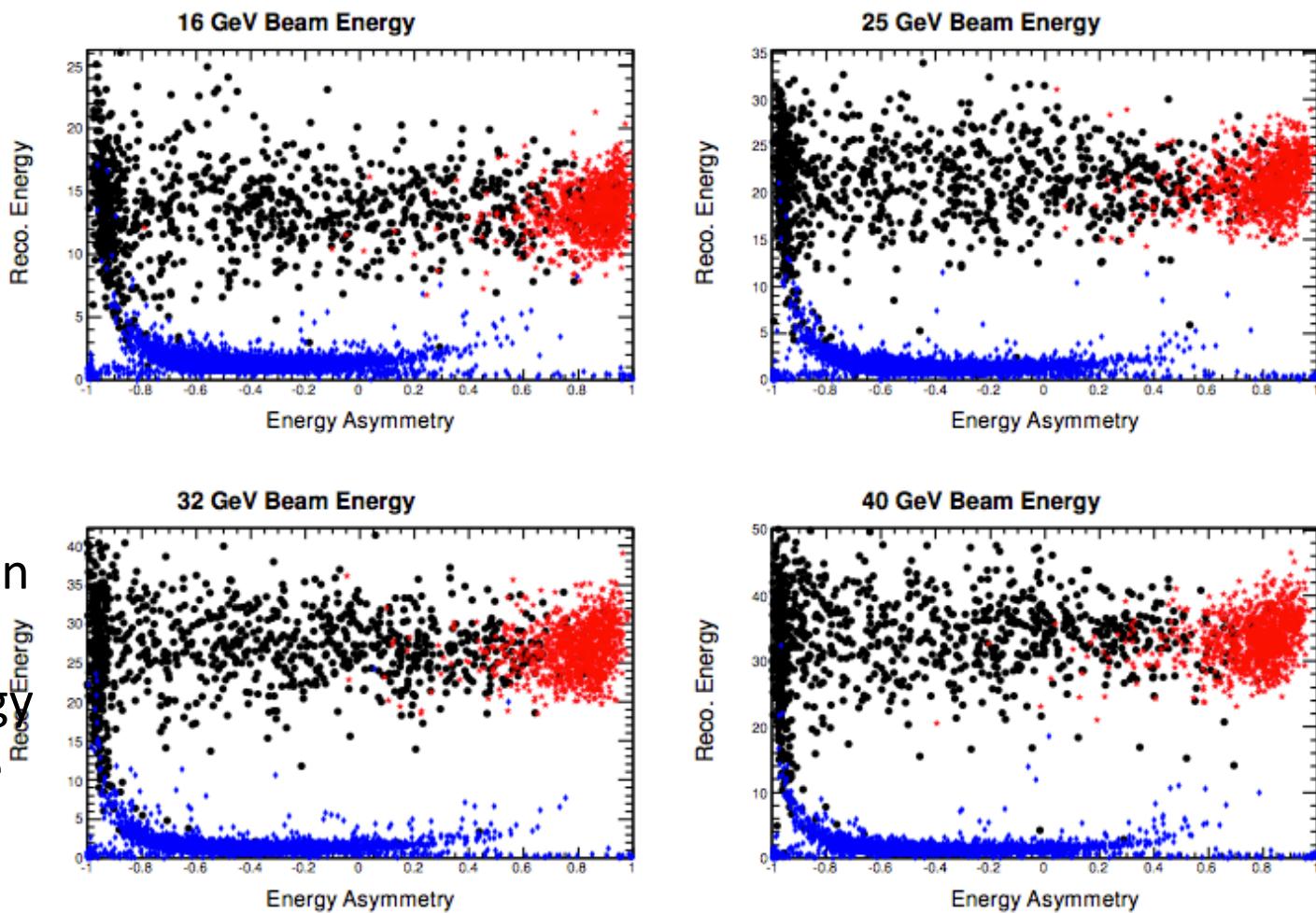


Energy Asymmetry and PID

Energy Asymmetry:

$$E_{asy} = \frac{E_1 - E_2}{E_1 + E_2}$$

E1, E2 are the total reconstructed energy in H1 and H2



Particle identification can be achieved by correcting the energy asymmetry with the total reconstructed energy in the detector.

Energy Resolution

Energy resolution was calculated for EM and hadronic showers at different tower energy suppression level (0, 5, 10, 15, 20 MeV) by fitting the energy spectra.

